



## Gulf of Mexico 2012 Expedition Tools for Classroom Explorers

# How to Use Multibeam Sonar Data



### Focus

Multibeam sonar

### Grade Level

5-12 (Physical Science/Earth Science); see Learning Procedure, Adaptation to Different Grade Levels

### Focus Question

How does multibeam sonar help explore Earth's deep ocean?



### Learning Objectives

- Students describe multibeam sonar.
- Students explain why the velocity of sound in water must be measured before maps can be created with the *Okeanos Explorer's* multibeam sonar system.
- Students interpret three-dimensional multibeam data of underwater features mapped by the *Okeanos Explorer*.



### Materials

- Copies of *Sonar Background Review Worksheet*, one copy for each student
- Copies of the *Introduction to Multibeam Imagery Worksheet*, one copy for each student group
- Computers with Internet access
- (Optional) Copies of the *Okeanos Explorer Multibeam Supplemental Datasheets* for one or more *Okeanos Explorer* cruises



### Audio-Visual Materials

- (Optional) Interactive white board or video projector

### Teaching Time

One or two 45-minute class periods; (more if students complete Supplemental Datasheets)

### Seating Arrangement

Groups of two to four students

### Maximum Number of Students

30

Image captions/credits on Page 2.

# lesson plan

## Key Words

NOAA Ship *Okeanos Explorer*  
Multibeam sonar  
Bathymetric survey

## Background Information

*Explanations and procedures in this lesson are written at a level appropriate to professional educators. In presenting and discussing this material with students, educators may need to adapt the language and instructional approach to styles that are best suited to specific student groups.*

### Images from Page 1 top to bottom:

Backdeck: Bobby Mohr, Tom Kok, and Jeff Williams discuss 'the plan' on the back deck. Image courtesy of the NOAA *Okeanos Explorer* Program.

<http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/logs/hires/mar21-2-hires.jpg>

Anchor resting on the top of the Site 15429 wreck. *Lophelia* coral is also visible.

After a great first marine archaeology dive on March 27, everyone was excited about exploring a second target. Site 15429 was initially located in 2009 with the National Institute for Undersea Science and Technology's (NIUST) *Eagle Ray* autonomous underwater vehicle (AUV). The data showed a potential vessel resting on the seafloor. The remotely operated vehicle (ROV) dive confirmed what several members of the Science Team expected. The wreck appears to be a hotspot for *Lophelia* coral. It was a great day for both the marine archaeologists and the biologists. Image courtesy of NOAA *Okeanos Explorer* Program.

[http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/logs/hires/mar29\\_hires.jpg](http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/logs/hires/mar29_hires.jpg)

Image of gridded bathymetry shown as a wireframe and draped over gridded backscatter data. Ever since the Team on Leg I of the Gulf of Mexico expedition mapped the DeSoto Canyon area in early March 2012, there was lots of speculation about one specific seafloor feature in approximately 400 meters of water. Not only did the feature seem to be the one spot of significant relief in an otherwise fairly flat area, but it also showed up in the backscatter data as a very 'hard' target. Image courtesy of NOAA *Okeanos Explorer* Program.

[http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/logs/hires/mar28\\_update\\_hires.jpg](http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/logs/hires/mar28_update_hires.jpg)

Through the power of technology, scientists on the ship and on shore are able to view and learn about the complex ecosystems in the Gulf of Mexico. Deep-sea corals flourish in the dark depths of the Gulf of Mexico, providing foundations that attract lush communities of other animals, including brittle stars, anemones, crabs, and fish. This diversity of life on the seafloor may be out of sight, but it is has been squarely on the minds of scientists seeking to determine the short- and long-term ecological impacts of the Deepwater Horizon oil spill. Image courtesy of the NOAA *Okeanos Explorer* Program.

<http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/logs/hires/mar24-2-hires.jpg>

On August 13, 2008, the NOAA Ship *Okeanos Explorer* was commissioned as "America's Ship for Ocean Exploration;" the only U.S. ship whose sole assignment is to systematically explore our largely unknown ocean for the purposes of discovery and the advancement of knowledge. To fulfill this mission, an exploration strategy is used that involves three major activities:

- Underway reconnaissance;
- Water column exploration; and
- Site characterization.

Underway reconnaissance involves mapping the ocean floor and water column while the ship is underway, and using other sensors to measure chemical and physical properties of seawater. Water column exploration involves making measurements of chemical and physical properties "from top to bottom" while the ship is stopped. In some cases these measurements may be made routinely at pre-selected locations, while in other cases they may be made to decide whether an area with suspected anomalies should be more thoroughly investigated. Site characterization involves more detailed exploration of a specific region, including obtaining high quality imagery, making measurements of chemical and physical seawater properties, and obtaining appropriate samples.

Key technologies involved with this strategy include:

- Multibeam sonar mapping system;
- CTD and other electronic sensors to measure chemical and physical seawater properties; and
- A Remotely Operated Vehicle (ROV) capable of obtaining high-quality imagery and samples in depths as great as 6,000 meters.

A fourth technological capability that is essential to the *Okeanos Explorer* exploration strategy is advanced broadband satellite communication. This capability provides the foundation for telepresence: technologies that allow people to observe and interact with events at a remote location. Telepresence allows live images to be transmitted from the seafloor to scientists ashore, classrooms,

newsrooms and living rooms, and opens new educational opportunities that are a major part of the *Okeanos Explorer's* mission for the advancement of knowledge. In addition, telepresence makes it possible for shipboard equipment to be controlled by scientists in shore-based Exploration Command Centers (ECCs). In this way, scientific expertise can be brought to the exploration team as soon as discoveries are made, and at a fraction of the cost of traditional oceanographic expeditions.

Sonar (which is short for SOund NAVigation and Ranging) systems are used to determine water depth, as well as to locate and identify underwater objects. In use, an acoustic signal or pulse of sound is transmitted into the water by a sort of underwater speaker known as a transducer. The transducer may be mounted on the hull of a ship, or may be towed in a container called a towfish. If the seafloor or other object is in the path of the sound pulse, the sound bounces off the object and returns an "echo" to the sonar transducer. The time elapsed between the emission of the sound pulse and the reception of the echo is used to calculate the distance of the object. Some sonar systems also measure the strength of the echo, and this information can be used to make inferences about some of the reflecting object's characteristics. Hard objects, for example, produce stronger echoes than softer objects. This is a general description of "active sonar." "Passive sonar" systems do not transmit sound pulses. Instead, they "listen" to sounds emitted from marine animals, ships, and other sources.

Multibeam sonar is one of the most powerful tools available for modern deep-sea exploration. A multibeam system uses multiple transducers pointing at different angles on either side of a ship to create a swath of signals. The *Okeanos Explorer* is equipped with a Kongsberg Simrad EM 302 multibeam system that can produce up to 864 depth soundings in a single swath, and over 10 swaths per second. The time interval between signal transmission and return echo arrival is used to estimate depth over the area of the swath. In some systems, the intensity of the return echo is also used to infer bottom characteristics that can be used for habitat mapping.

In addition to high-resolution maps, multibeam data can be used to create three-dimensional models or even "fly-by" videos that simulate a trip across the area being mapped. For a fascinating example of this, see <http://oceanexplorer.noaa.gov/explorations/02fire/logs/jul08/media/sm2k.html>. This 3D fly-through movie shows the seafloor in the Magic Mountain area of Explorer Ridge (near the coast of Vancouver, British Columbia) where there are active hydrothermal vents. To see what the vents look like, you can view other fly-throughs of the same area at <http://oceanexplorer.noaa.gov/explorations/02fire/logs/magicmountain>. Recently, a new generation of multibeam sonars has been developed that are able to map features in the water column as



- Consider whether you want to show students multibeam imagery as an educator demonstration using the iView4D software described on the *Introduction to Multibeam Imagery Worksheet*. The techniques described on the *Worksheet* may be used to view images referenced in *Okeanos Explorer Multibeam Sonar Supplemental Datasheets* as well as the file referenced on the *Worksheet*. If you decide to do this demonstration, complete Step 1d and Step 1e.
- **For Grades 5-6** – Consider using the activity provided in the “Wet Maps” lesson ([http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/hdwe\\_56\\_wetmaps.pdf](http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/hdwe_56_wetmaps.pdf)) targeted toward grades 5-6 in which students simulate a multibeam sonar system to create a three-dimensional map of a model seafloor.
- **For Grades 7-8** – Consider using the activity provided in the “Mapping the Deep Ocean Floor” lesson ([http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/hdwe\\_78\\_oceanfloor.pdf](http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/hdwe_78_oceanfloor.pdf)) targeted toward grades 7-8 in which students create a three-dimensional graph called a surface plot using depth data from a multibeam sonar survey conducted aboard the NOAA Ship *Okeanos Explorer*.

1. To prepare for this lesson,

a. Review:

- Introductory essays for the INDEX-SATAL 2010 Expedition (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/welcome.html>);
- *Minding the Multibeam at Midnight* by Colleen Peters (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/aug05/aug05.html>); and
- *State of the Art Seafloor Survey* by Meme Lobecker and Elaine Stuart (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july31/july31.html>).

b. Review background information (above) about the *Okeanos Explorer* exploration strategy and technologies.

c. If desired, download images to accompany discussions in Step 2. You may also want to download this “before and after” image to illustrate the capabilities of multibeam sonar:

[http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/em302\\_before\\_after\\_hires.jpg](http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/em302_before_after_hires.jpg), as well as one or more of the animations referenced above to accompany discussions in Step 3:

<http://oceanexplorer.noaa.gov/explorations/02fire/logs/jul08/media/sm2k.html>; AND

<http://oceanexplorer.noaa.gov/explorations/02fire/logs/magicmountain>

d. Review background information on multibeam sonar technology and questions on the *Sonar Background Review Worksheet* and *Introduction to Multibeam Imagery Worksheet* and, optionally, one

or more *Okeanos Explorer Multibeam Supplemental Datasheets*. Make copies of the *Sonar Background Review Worksheet* for each student, and copies of the *Introduction to Multibeam Imagery Worksheet* for each student group.

e. Download the iView4D software from <http://www.ivs3d.com/products/iview4d/>, and Download the data file INDEX2010\_mb\_1.sd from [http://oceanexplorer.noaa.gov/okeanos/edu/resources/media/INDEX2010\\_mb\\_1.sd](http://oceanexplorer.noaa.gov/okeanos/edu/resources/media/INDEX2010_mb_1.sd) and install these on computers that students will be using to complete the Worksheet activity. Alternatively, you may have students download these resources onto their own computers.

2. Provide each student with a copy of the *Sonar Background Review Worksheet* as homework in preparation for the remainder of this lesson.
3. Briefly introduce the NOAA Ship *Okeanos Explorer*, which is the only U.S. ship whose sole assignment is to systematically explore Earth's largely unknown ocean for the purposes of discovery and the advancement of knowledge. Discuss why this kind of exploration is important (for background information, please see the lesson, *Earth's Ocean is 95% Unexplored: So What?*; [http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/so\\_what.pdf](http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/so_what.pdf)). Review the overall strategy for ocean exploration used aboard *Okeanos Explorer*, and the primary technologies involved with this strategy (see background information above).
4. Review students' answers to questions on the *Sonar Background Review Worksheet*. The following points should be included:
  - Sound waves in water move as compression waves, while electromagnetic waves are transverse waves.
  - The speed of sound waves travelling in water is affected by conditions of the water such as salinity, pressure, and temperature; the speed of sound waves under a particular set of these conditions is called the local speed of sound. In the ocean, the speed of sound is about 1,500 meters per second.
  - The physical distance between two consecutive pressure fronts in a sound wave is wavelength.
  - The number of pressure fronts that pass a stationary point in a certain amount of time is the frequency of the wave.
  - The mathematical relationship between wavelength and frequency is:  
$$\text{speed of sound} = \text{frequency} \times \text{wavelength}$$

Typically, wavelength is measured in meters (m), and frequency is measured in cycles per second (Hz), so units for the speed of sound are meters per second.

- When a sound wave moving through water encounters a change in temperature, the local speed of sound and wavelength change, but frequency remains constant.
  - When a sound wave moves through the water, energy is the thing that actually moves.
  - If one sound wave induces a greater pressure change than another sound wave, the first sound wave contains more energy.
  - The pressure caused by a sound wave is directly related to the amplitude of the wave, which is related to the acoustic energy of the wave; higher amplitude waves contain more energy.
  - When a sound wave moves through water, it gradually loses some of its energy, so its amplitude is reduced.
  - Sound waves with higher frequencies lose energy more rapidly than lower frequency sound.
  - When a sound wave moving through water encounters another medium, some of its energy is transferred into the new medium, some of it is reflected off the surface of the medium, and the rest is scattered in all directions. How much energy is reflected and how much is scattered depends on the characteristics of the medium and the angle at which the wave strikes the medium (angle of incidence). The energy that is reflected maintains the frequency characteristics of the original sound wave.
5. Ask students what they know about sonar, and provide additional information as necessary. Be sure students understand that sonar (which stands for SOund NAvigation and Ranging) uses an acoustic signal or pulse of sound that is transmitted into the water by a sort of underwater speaker known as a transducer. Transducers may be mounted on the hull of a ship, or may be towed in a container called a towfish. If the seafloor or other object is in the path of the sound pulse, the sound bounces off the object and returns an “echo” to the sonar transducer. The time elapsed between the emission of the sound pulse and the reception of the echo is used to calculate the distance of the object. Since the time between transmission of a pulse and the return of its echo is the time it takes the sound to travel to the bottom and back, if we know this time and the local speed of sound we can calculate the distance to the bottom

(this distance is called range). The time measured between pulse transmission and echo return is the “round trip” time, so the pulse has travelled twice the range during this time. For this reason, the general formula for range is:

$$\text{range} = (1/2) (\text{local speed of sound}) (\text{echo time})$$

A multibeam sonar system uses multiple transducers pointing at different angles on either side of a ship to create a swath of signals. The time interval between signal transmission and return echo arrival is used to estimate depth over the area of the swath. In addition to high-resolution maps, multibeam data can be used to create three-dimensional models or even “fly-through” videos that simulate a trip across the area being mapped. You may want to show one or more of the video clips referenced in Step 1c.

Describe the role of multibeam sonar in ocean exploration aboard *Okeanos Explorer*. The image [http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/em302\\_before\\_after\\_hires.jpg](http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/em302_before_after_hires.jpg) shows how much the *Okeanos Explorer*'s EM302 mapping system adds to what we know about seafloor terrain. Students should realize that this is the key technology for the “reconnaissance” component of the overall exploration strategy, and provides the “big picture” view as explorers look for anomalies.

Show this image [http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/xbt\\_cast\\_hires.jpg](http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/xbt_cast_hires.jpg) in which two scientists are conducting an XBT cast during the INDEX-SATAL 2010 Expedition. Be sure students understand that an XBT is an “expendable bathythermograph” which measures temperature through the water column. Ask students why this information is important to accurate multibeam operations. Students should realize that temperature affects the local speed of sound, which we have to know in order to calculate range as described above.

6. Provide each student group with a copy of the *Introduction to Multibeam Imagery Worksheet*, and ensure that students have access to the software and file referenced in Step 1e. Tell students that this activity is intended to familiarize them with multibeam imagery and how it can be manipulated to answer basic questions about features on the ocean floor. You may also want to mention that this skill will enable them to investigate additional images that will be available from future *Okeanos Explorer* missions.

7. When students have answered questions on the *Worksheet*, lead a discussion of their results. This discussion should include:

- The northern and southern latitude boundaries for the image are about  $4^{\circ} 44' 49''$  N latitude and about  $4^{\circ} 36' 10''$  N latitude respectively. Reading the numbers on the latitude and longitude scales can be difficult; an easier way to find this information is to rotate the image so that we are directly overhead, then placing the cursor near the edges of the image and reading the latitude and longitude coordinates from the window on the lower left.
- The eastern and western longitude boundaries for this image are about  $125^{\circ} 9' 39''$  E longitude and about  $125^{\circ} 01' 02''$  E longitude, respectively.
- The deepest parts of the image are approximately 5,400 meters deep (near the northwestern edge of the image).
- The shallowest part of this volcano is about 1,870 meters deep.
- We can estimate the diameter of the volcano by finding the north and south latitude boundaries of the base. If we use the edge of the light blue shading as the base (the actual base is deeper than this, but is not completely shown in the image; students may select a different outer boundary, in which case the following calculations will need to be adjusted, but the calculation technique is the same), the northern latitude boundary is about  $4^{\circ} 44' 21''$  N, and the southern latitude boundary is about  $4^{\circ} 36' 16''$  N. The difference between these numbers is  $8' 5''$ . Since one minute of arc is equal to 60 seconds of arc, 5 seconds is equal to
 
$$5 \div 60 = 0.083 \text{ minute}$$
 So the diameter is approximately 8.083 minutes, which is equal to
 
$$8.083 \text{ nautical miles, which is equivalent to}$$

$$8.083 \text{ nm} \cdot 1.852 \text{ km} = 14.97 \text{ km}$$
- To calculate the approximate slope of the volcano using the triangle hint, we need to know the diameter and height of the volcano. If we continue to use the edge of the light blue shading as the base, the depth at this point is about 4,539 m. Since the shallowest part of the volcano is about 1,870 m, its height is approximately 2,669 m. If the base of the triangle is one-half the volcano's diameter, this is equal to
 
$$0.5 \cdot 14.97 \text{ km} = 7.485 \text{ km} = 7,485 \text{ m}$$

The slope of the volcano is the angle between the side of the triangle and its base. The tangent of this angle equal to the height divided by the base:

$$\tan \text{ slope} = 2,669 \text{ m} \div 7,485 \text{ m} = 0.357$$

The arctangent of 0.357 is the angle of the slope, which is equal to 19.6 degrees. If we set the vertical exaggeration in the upper left window to 1.0 (no exaggeration), this estimation looks reasonable.

- The deep valley on the southwestern side of the volcano, running roughly between  $4^{\circ} 40' 24''$  N,  $125^{\circ} 5' 11''$  E and  $4^{\circ} 39' 38''$  N,  $125^{\circ} 4' 44''$  E appears to have relatively steep topography and would be an interesting place to look for biological organisms.

### The BRIDGE Connection

[www.vims.edu/bridge/](http://www.vims.edu/bridge/) – Scroll over “Ocean Science Topics” in the menu on the side of the page, then “Habitats” then select “Deep Ocean” for activities and links about deep ocean ecosystems. Scroll over “Research and Data Connections” in the menu on the side of the page, then select “Virtual Expeditions” for activities and links to online activities about various types of exploration activities.

### The “Me” Connection

Have students write a brief essay describing a backpacking trip across a landscape having the topography shown in the multibeam image used for the *Worksheet* activity.

### Connections to Other Subjects

English/Language Arts, Mathematics, Social Studies

### Assessment

Students’ answers to worksheet questions and class discussions provide opportunities for assessment.

### Extensions

Visit the *Okeanos Explorer* Atlas ([http://www.ncddc.noaa.gov/website/google\\_maps/OkeanosExplorer/mapsOkeanos.htm](http://www.ncddc.noaa.gov/website/google_maps/OkeanosExplorer/mapsOkeanos.htm)) and Web page (<http://oceanexplorer.noaa.gov/okeanos/welcome.html>) for reports, images, and other products from *Okeanos Explorer* cruises.

### Other Relevant Lesson Plans from NOAA’s Ocean Exploration Program

**Earth’s Ocean is 95% Unexplored: So What?  
(from the INDEX-SATAL 2010 Expedition)**

[http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/so\\_what.pdf](http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/so_what.pdf)

Focus: Importance of deep ocean exploration (Grades 5-6; Life Science/Earth Science)

Students describe at least three different deep ocean ecosystems; explain at least three reasons for exploring Earth’s deep ocean; and

explain at least three ways that deep ocean ecosystems may benefit humans.

The following lessons are included in the *NOAA Ship Okeanos Explorer Education Materials Collection Volume 2: How Do We Explore?* <http://oceanexplorer.noaa.gov/okeanos/edu/collection/hdwe.html>.

### **To Explore Strange New Worlds**

[http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/hdwe\\_78\\_toexplore.pdf](http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/hdwe_78_toexplore.pdf)

Focus: Strategies for exploring unknown areas on Earth (Grades 5-6; Life Science/Physical Science/Earth Science)

Students describe requirements for explorations of unknown areas on Earth; discuss factors that influenced exploration strategies of the Lewis and Clark and *Challenger* Expeditions; describe the overall exploration strategy used aboard the NOAA Ship *Okeanos Explorer*; and describe how fractal geometry models natural systems, and how scale influences exploration strategy and results.

### **Wet Maps**

[http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/hdwe\\_56\\_wetmaps.pdf](http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/hdwe_56_wetmaps.pdf)

Focus: Bathymetric mapping (Grades 5-6; Physical Science/Earth Science)

Students describe three types of bathymetric map, and discuss how each type may be used by ocean explorers; compare and contrast bathymetric mapping technologies; explain why multibeam mapping is used aboard the *Okeanos Explorer*; and simulate a multibeam sonar system to create a three-dimensional map of a model seafloor.

### **Mapping the Deep Ocean Floor**

[http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/hdwe\\_78\\_oceanfloor.pdf](http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/hdwe_78_oceanfloor.pdf)

Focus: Bathymetric mapping (Grades 7-8; Physical Science/Earth Science)

Students explain the advantages of multibeam sonar, and its role in the exploration strategy used aboard the *Okeanos Explorer*; and use data from the *Okeanos Explorer* to create a bathymetric map.

### Sound Pictures

(from the Cradle of the Earthquake: Exploring the Underwater San Andreas Fault 2010 Expedition)

<http://oceanexplorer.noaa.gov/explorations/10sanandreas/background/edu/media/soundpics912.pdf>

Focus: Sonar (Grades 9-12; Physical Science)

Students explain the concept of sonar, describe the major components of a sonar system, explain how multibeam and sidescan sonar systems are useful to ocean explorers, and simulate sonar operation using a motion detector and a graphing calculator.

### Other Resources

*The Web links below are provided for informational purposes only. Links outside of Ocean Explorer have been checked at the time of this page's publication, but the linking sites may become outdated or non-operational over time.*

<http://oceanexplorer.noaa.gov/oceanos/edu/welcome.html> – Web page for the *Oceanos Explorer* Education Materials Collection

Anonymous. 2002. Magic Mountain Virtual site [Internet]. NOAA Office of Ocean Exploration and Research [cited January 14, 2011]. Available from: <http://oceanexplorer.noaa.gov/explorations/02fire/logs/magicmountain/welcome.html>; Links to virtual fly-throughs and panoramas of the Magic Mountain hydrothermal vent site on Explorer Ridge in the NE Pacific Ocean, where two tectonic plates are spreading apart and there is active eruption of submarine volcanoes

Anonymous. 2000. Multibeam Sonar Theory of Operation [Internet]. L-3 Communications SeaBeam Instruments [cited January 24, 2011]. Available from: <http://www.ldeo.columbia.edu/res/pi/MB-System/sonarfunction/SeaBeamMultibeamTheoryOperation.pdf>

Doucet M., C. Ware, R. Arsenault, T. Weber, M. Malik, L. Mayer, and L. Gee. Advanced Mid-Water Tools for 4D Marine Data Fusion and Analysis. Paper presented at OCEANS 2009, Biloxi, Mississippi, October 26-29, 2009; available online at <http://www.ivs3d.com/news/PID985675.pdf>

Gardner, J. V., M. A. Malik, and S. Walker 2009. Plume 1400 Meters High Discovered at the Seafloor off the Northern California Margin. EOS Transactions, American Geophysical Union, 90(32): 275 - 275.

**Correlations to A Framework for K-12 Science Education:  
Practices, Crosscutting Concepts, and Core Ideas**

**Framework for K-12 Science Education**

**Dimension 1. Scientific and Engineering Practices**

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

**Dimension 2. Crosscutting Concepts**

1. Patterns
2. Cause and effect: Mechanism and explanation
3. Scale, proportion, and quantity
4. Systems and system models

**Dimension 3. Disciplinary Core Ideas**

**Physical Sciences**

- Core Idea PS4: Waves and Their Applications in Technologies for Information Transfer
  - PS4.A: Wave Properties
  - PS4.C: Information Technologies and Instrumentation

**Earth and Space Sciences**

- Core Idea ESS2: Earth’s Systems
  - ESS2.A: Earth Materials and Systems
  - ESS2.B: Plate Tectonics and Large-Scale System Interactions

**Engineering, Technology, and the Applications of Science**

- Core Idea ETS2: Links Among Engineering, Technology, Science, and Society
  - ETS2.A: Interdependence of Science, Engineering, and Technology

**Correlations to Common Core State Standards for Mathematics**

Grade 5 - 8: Geometry.

High School: Modeling; Trigonometric Functions

**Correlations to Common Core State Standards for English  
Language Arts**

Grades 6-12 Reading: Informational Text

RI.9-10.4. Determine the meaning of words and phrases as they are used in a text, including figurative, connotative, and technical meanings.

Grades 6-12 Literacy in History/Social Studies, Science, & Technical Subjects: Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.

## Ocean Literacy Essential Principles and Fundamental Concepts

### Essential Principle 1.

The Earth has one big ocean with many features.

*Fundamental Concept b.* An ocean basin's size, shape and features (such as islands, trenches, mid-ocean ridges, rift valleys) vary due to the movement of Earth's lithospheric plates. Earth's highest peaks, deepest valleys and flattest vast plains are all in the ocean.

### Essential Principle 5.

The ocean supports a great diversity of life and ecosystems.

*Fundamental Concept f.* Ocean habitats are defined by environmental factors. Due to interactions of abiotic factors such as salinity, temperature, oxygen, pH, light, nutrients, pressure, substrate and circulation, ocean life is not evenly distributed temporally or spatially, i.e., it is "patchy". Some regions of the ocean support more diverse and abundant life than anywhere on Earth, while much of the ocean is considered a desert.

*Fundamental Concept g.* There are deep ocean ecosystems that are independent of energy from sunlight and photosynthetic organisms. Hydrothermal vents, submarine hot springs, and methane cold seeps rely only on chemical energy and chemosynthetic organisms to support life.

### Essential Principle 6.

The ocean and humans are inextricably interconnected.

*Fundamental Concept b.* From the ocean we get foods, medicines, and mineral and energy resources. In addition, it provides jobs, supports our nation's economy, serves as a highway for transportation of goods and people, and plays a role in national security.

### Essential Principle 7.

The ocean is largely unexplored.

*Fundamental Concept a.* The ocean is the last and largest unexplored place on Earth—less than 5% of it has been explored. This is the great frontier for the next generation's explorers and researchers, where they will find great opportunities for inquiry and investigation.

*Fundamental Concept b.* Understanding the ocean is more than a matter of curiosity. Exploration, inquiry and study are required to better understand ocean systems and processes.

*Fundamental Concept d.* New technologies, sensors and tools are expanding our ability to explore the ocean. Ocean scientists are relying more and more on satellites, drifters, buoys, subsea observatories and unmanned submersibles.

*Fundamental Concept f.* Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.

### **Send Us Your Feedback**

In addition to consultation with expedition scientists, the development of lesson plans and other education products is guided by comments and suggestions from educators and others who use these materials. Please send questions and comments about these materials to:

[oceanexeducation@noaa.gov](mailto:oceanexeducation@noaa.gov).

### **For More Information**

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### **Credit**

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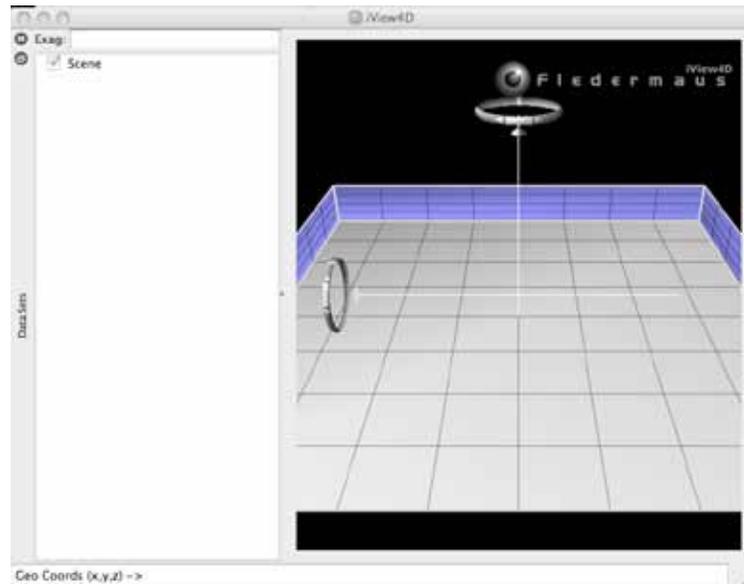
## Sonar Background Review Worksheet

1. How are sound waves in water different from electromagnetic waves such as light or radio waves?
2. What are some conditions that affect the speed of sound waves travelling in water?
3. Sound waves may be thought of as a sequence of moving pressure fronts. What is the term for the physical distance between two consecutive pressure fronts?
4. What is the term for the number of pressure fronts that pass a stationary point in a certain amount of time?
5. What is the mathematical relationship between the properties described in Questions 3 and 4?
6. When a sound wave moving through water encounters a change in temperature, what happens to the properties described in Questions 3 and 4?
7. When a sound wave moves through the water, what is it that is actually moving?
8. Instruments called hydrophones measure the changes in pressure caused by the pressure fronts of a sound wave. If one sound wave is found to cause greater pressure changes than another sound wave, what does this indicate about the two waves?
9. The pressure caused by a sound wave is directly related to a third property of waves. What is this property?
10. What happens to the property identified in Question 9 as a sound wave moves through water?
11. How is the effect identified in Question 10 related to the property identified in Question 4?
12. When a sound wave moving through water encounters another medium, such as rock or sand, what are three things that happen to the quantity identified in Question 7.

## Introduction to Multibeam Imagery Worksheet

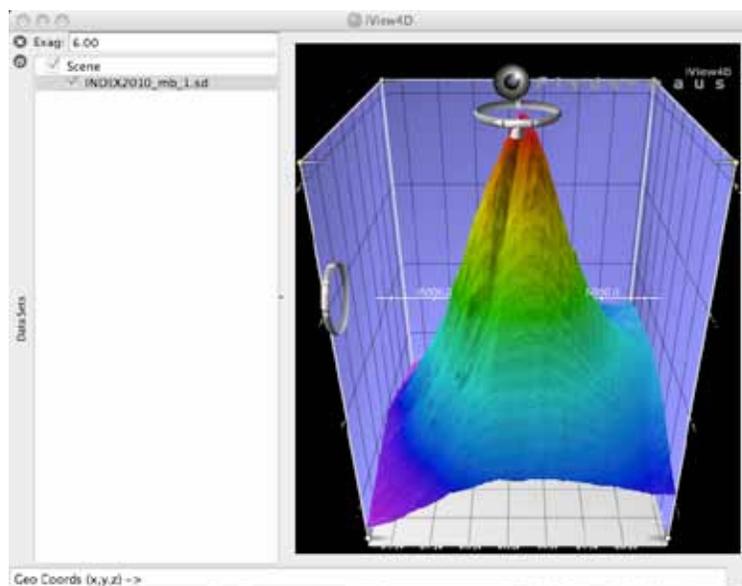
1. Launch the iView4D software. Your screen should resemble Figure 1. Note the Rotation Control Rings near the top center and mid-left side of the screen. If your screen doesn't look like Figure 1, be sure "Bounds" is checked under the "View" drop-down menu.

Figure 1.



2. Open the file, INDEX2010\_mb\_1.sd. Now your screen should resemble Figure 2. This is a multibeam sonar image of the Kawio Barat submarine volcano, which was identified as a priority for exploration during the INDEX-SATAL 2010 Expedition.

Figure 2.



The ocean floor is shown as a three-dimension image. The x-axis represents longitude, the y-axis represents latitude, and the z-axis represents depth. When you move the cursor over the image, the window near the bottom of the screen shows the geo coordinates (x, y, and z) for the location beneath the cursor.

The Rotation Control Ring near the top allows you to rotate the image around the vertical axis, and the Rotation Control Ring on the left allows you to rotate the image around the horizontal axis. Alternatively, you can left-click (simple click on a Macintosh platform) and drag up or down to rotate the image around the horizontal axis, or left-click and drag left or right to rotate the image around the vertical axis.

You can zoom the image by right-clicking (or control-clicking on a Macintosh platform) in the middle of the image then dragging to zoom in or out.

To bring a different part of the image to the center of the window, place the cursor over the part of the image that you want to be the center point and right-click (control-click on a Macintosh platform). The view will now be centered on the point that you clicked.

Some images use “vertical exaggeration” to show features more clearly. This means that the vertical scale is larger than the horizontal scale so vertical features are magnified. You can control the amount of vertical exaggeration by clicking and dragging the cone-shaped object on the vertical scale line near the middle of the image. Numbers on the scale lines show the relative horizontal and vertical scales.

For additional help or information click “Navigating the Scene...” under the “Help” drop-down menu.

Experiment with these controls to find out how they allow you to manipulate the image, then answer the following questions:

3. What are the northern and southern latitude boundaries for this image? (Hint: The Rotation Control Ring on the left allows you to rotate the image so that you are looking straight down.)
4. What are the eastern and western longitude boundaries for this image?
5. The deepest parts of the image are approximately how deep?
6. How deep is the shallowest part of this volcano? (Hint: Increasing the vertical exaggeration will make it easier to spot the shallowest portion.)
7. What is the approximate diameter of the volcano at its base? (Hint: One minute of latitude is equal to one nautical mile, which is equal to 1.852 km.)
8. What is the approximate slope of the volcano? (Hint: Think of the volcano as a right triangle whose base is one-half the volcano’s diameter.)
9. Often, areas where local topography is steep or very changeable will also be areas that have a variety of biological organisms. What is the approximate location of an area on the volcano that seems to have this kind of topography? (Hint: This is easier to see without vertical exaggeration.)